STUDIES ON IONOSPHERIC ABSORPTION*

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ABSTRACT This paper discusses briefly the phenomenon of ionospheric absorption of radio waves in their passage through the ionospheric regions. Results of observations made at Calcutta on the variation of ionospheric absorption with that of wave frequency are described. The results show that in addition to the losses due to collisions there is a marked increase in attenuation near the critical frequencies of the layers due to partial penetration of the wave energy. Presence of sporadic E layers also causes increased attenuation of F echoes by partial reflection and scattering. When there is magneto-ionic splitting, the extraordinary component is always found to suffer higher attenuation as predicted by theory. On certain nights presence of sporadic D's was noticed. This caused high absorption on all frequencies in the short wave range. The sporadic D's are found to be associated with sporadic E and thunderstorms.

1 INTRODUCTION

Solution of practical problems of radio communication between distant points *via* ionosphere, necessitates a knowledge not only of the M. U. F.'s of the various ionospheric layers (which depend on the corresponding vertical incidence penetration frequencies) but also of the losses suffered by the radio wave in its passage through these layers. For example, a knowledge of the magnitude of the ionospheric loss is required for the determination of the power that must be used in a transmitter in order that the signals may reach a given distant station. Such knowledge is also required to estimate the maximum power on which a station may be allowed to work, in order that it may not interfere with the transmissions from other distant stations working on the same frequency.

Unfortunately, though observations on vertical incidence penetration frequencies are now made regularly on a fairly world wide scale, very little data are available for the absorption characteristics of the different ionospheric layers. Further, of the few exprimental investigations on absorption that have been carried out so far, the majority are for the stations situated at higher latitudes only. There are very few experimental result for the equatorial regions. Since the latitude of Calcutta is low (geograghical latitude 22°33'N ; magnetic latitude 13°N), it was thought that observations on ionospheric absorption made here would fill the gap. A systematic programme of observation has, therefore, been arranged at the ionospheric

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station at Calcutta and the results will be published in due course. In the present communication results of some observations on the variation of reflection coefficient with frequency (for vertical incidence, white, *et. al.* 1930, 1936) for frequencies from two megacycles upwards, will be described and discussed.

It will be helpful, if we first briefly discuss the causes of attenuation of received radio waves in their passage through the ionospheric layers.

2. CAUSES OF ATTENUATION OF INDIRECTLY RECEIVED RADIO WAVES

The losses in energy leading to the attenuation of radio waves in their passage through the ionospheric layers may be listed as follows :

(1) *Loss due to collision.* The electrons in the ionosphere are set into oscillation by the incident radio wave. The energy of the oscillating electrons, which would otherwise have gone back to the wave field by re-radiation, is dissipated if there are collisions.

(2) *Loss due to partial reflection.* Sometimes partial reflection takes place from regions of large ionization density gradient or thin layers. The amplitude of the reflected wave is decreased, since a portion of the wave energy penetrates through the ionized region and is lost. Such partial penetration also takes place near the critical frequency of an ionized layer.

(3) *Losses due to irregularities.* Irregularities present in the ionosphere, *e.g.* ionospheric clouds, sporadic layers etc., scatter the incident radio wave and thus decrease the amplitude of the reflected wave. Further, the phases of the scattered waves change in a random manner and the waves scattered from different regions may reach the receiving point in phase or out of phase. Thus, the amplitude of the received signal changes rapidly with time, which causes fading. For the case in which there is an adding up in phase, the strength of the received signal may even sometimes be greater than that expected for propagation in free space (focusing effect, Rawer. *et al*, 1951)

The losses due to all the above causes may be lumped together and may be regarded as loss by "absorption" in the ionosphere. We can thus speak of an effective "absorption coefficient", K, per unit length, so that the overall absorption suffered by the wave is given by $\int K ds$, where ds is an element of the ray path and the integration is carried out over the whole length of the path. The 'apparent reflection coefficient', ρ, which is defined as the ratio of the amplitudes of the reflected to incident field strength, is thus given by

$$-\log_e \rho = \int K ds \qquad \ldots \quad (1)$$

As the loss due to (1) is the most important and is always present, let us consider it in some detail.

The wave in its passage through the ionosphere, suffers deviation before returning to earth. It is convenient to consider separately the losses suffered (*i*) in the main deviating region and (*ii*) in the lower region where there is little deviation.

(*i*) *Deviative absorption.* The wave is deviated and gets reflected from this region. The refractive index in this region is less than unity, and, if there be collisions leading to absorption of energy, the refractive index becomes complex. Calculation of ionospheric absorption in a deviating region, considering the Chapman distribution of ionization density, is very involved. In practice, a parabolic approximation to the Chapman distribution is always used. Hacke (1948) and Hacke and Keiso (1948) have shown that a better result is obtained if the Chapman layer is represented by two parabolas – one representing the ionization density below the point of inflection in the Chapman distribution curve and the other giving the ionization above this point.

The deviative absorption is of special importance in the case of long and very long waves, as these are reflected from the lowermost ionized region, namely the D region, and suffer only this type of absorption. The absorption is generally high as the collisional frequency in this region is greater than the wave frequency. A peculiar feature of the attenuation of such waves is that as the freqnency is lowered the attenuation at first increases being maximum at about 100 kc/s. (Best, *et al*, 1936). However, in the very long wave band (about 16 kc/s) there is strong reflection throghout day and night (Beynon, 1948). This shows that there is a transition in propagation properties between these two frequencies. The height of reflection of long waves generally lies between 60 and 80 kms. (Budden, 1951 ; Bracewell, 1948 ; Mitra, 1951). With decrease of sun's zenith angle, the longwave absorption increases, as the ionization of the D layer penetrates to lower levels where collisional frequency is high.

The deviative absorption is of less importance in the short wave range on which the long distance radio communication is generally carried out. At these frequencies, the reflection takes place from the E and the F layers where the collisional frequency is low. As such, most of the absorption takes place in the lower non-deviating D region.

(*ii*) *Non-deviative absorption (D region).* As mentioned above, short and medium waves reflected from the higher ionized regions (E or F layers) suffer non-deviative absorption in the lower D layer, through which the waves have to pass and repass. The D layer absorption for these waves is particularly effective during day time (excepting near the critical frequency of the reflecting E or F layer), as during day time, the ionization reaches low levels (even upto 60 km.) where the collisional frequency is high.

According to the magneto-ionic dispersion formula, the propagation through the ionosphere is said to be quasi-transverse or quasi-longitudinal acdording as (Mitra, 1952) :

$$\left| \frac{\gamma_T^4}{4(1+\alpha+jB)^2} \right| > \text{ or } < |\gamma^2_L|$$

It can be shown that for short waves, under collisional conditions in the D layer, the propagation is quasi-longitudinal. Hence, the non-deviative absorption in the region is proportional to

$$(f \pm f_H \cos\theta)^2$$

where f is the wave frequency, f_H is the gyrofrequency and θ is the angle between the direction of propagation and the direction of the terrestrial magnetic field (+ sign refers to the ordinary component and − sign refers to the extraodinary component (Jaegar, 1947). For vertical incidence, θ is the complement of the angle of magnetic dip η and hence the absorption is proportional to

$$(f \pm f_H \sin\eta)^2 \qquad \ldots \quad (2)$$

This relation is approximately obeyed in the short wave range.

The supposition that the absorption of waves reflected during day time from the E or the F region is due to losses in the D region is supported by the fact that the diurnal and seasonal variations of waves so reflected, differ from those expected from a normal E region. Hence the absorption is ascribed to the D layer, where the distribution of ionization and the equilibrium processes differ from those in the E region (Mitra, 1951). Appleton (1938) has shown that for a Chapman layer, the variation of absorption with sun's zenith angle χ when $\chi < 85°$ is proportional to $\cos^{3/2}\chi$. In general, the diurnal variation may be said to be proportional to $\cos^n\chi$. The reported experimental values of n vary between 0.5 and 2.0 A value of $n=1$ (Rep. Rad. Res., 1950) represents the diurnal variation fairly well.

In addition to the diurnal and seasonal variations of ionospheric absorption with sun's zenith angle, the D region absorption has also been found to vary with the solar activity, (Benner, 1951) there being an increase by a factor of about 1.5 between sunspot numbers zero and hundred. Further, a 27-day cycle of variation of absorption, coinciding with the rotation period fo the sun, has been reported.

Abnormal absorption. Besides regular absorption effects noted above, certain abnormal changes of ionospheric absorption are also observed. These include increased absorption associated with sudden outbursts of solar activity and of solar particle emanations, including the absorption effects manifest during ionospheric storms and sudden ionospheric disturbances, and also the absorption continually present in the auroral belts (Tayler, 1948).

Absorption in oblique propagation. The first author to make a detailed study of absorption in oblique propagation was Martyn (1951), who showed that for an angle of incidence i_0, the absorption is sec i_0 times greater than the vertical incidence case. His formula may be written as

$$[-\log \rho_e]_{f, i_0} = \cos i_0 [-\log_e \rho]_{f \cos i_0, 0}$$

The experimental values are generally greater than this. Booker (1940) made a more detailed study, taking into consideration the earth's magnetic field, but his calculations are laborious.

From their studies, Appleton, Beynon and Piggott (1948) have concluded that there is another factor besides collisional friction which is operative in causing the loss. This factor is scattering or partial reflection from the sporadic E layers, as stated earlier. When more than one reflection can be observed, the oblique incidence experiments give a simple method of separating frictional and scattering losses in the ionosphere.

3. OBSERVATIONS ON THE VARIATION OF ABSORPTION WITH FREQUENCY

Method of measurement. The mesurement of the absorption was made by measuring the strength of the echoes of signals emitted from a Breit and Tuve type pulse transmitter, modulated with a pulse of repetition frequency 50 c/s and of duration 200 microseconds. The echoes were received in the same room by a communication type receiver. Both the transmitter and the receiver employed inverted L type aerials. The echoes received were displayed on the screen of the cathode ray oscillograph in the ususal manner, the amplitude being visually measured by comparison with a scale on the screen of the oscillograph. With the emtting and receiving equipments in the same room, it was not possible to make use of the direct signal as the reference signal. When opportunity occurred, the electromotive forces due to the first and second order reflections were compared and these were used to calibrate the apparatus so as to give values of absorption even when only first order reflections were present. For this to be possible, the transmitting and receiving systems, including the aerials and aerial couplings, had to be maintained constant in every respect. The output of the transmitter was noted by readings of the transmitter plate current (which was kept constant), while the frequent recalibration of the receiver served as a check of it.

The amplitude of the echo is always subject to a random variation due to various causes. In order to find the average amplitude, each reading of absorption was based on eighteen readings taken at intervals of ten seconds. The arithmatic mean value was taken to be the average amplitude (Banerjee, 1951).

The reflection coefficient, as measured, is the so-called apparent reflection coefficient which takes into account the overall absorption by the wave in the deviating and the non-deviating regions, and the energy lost in scattering, if any. Further, remembering that the signal strength of the receiving aerial depends on the polarization of the receiving wave, it also includes the effect of changes in the polarization of the echo.

When both the first and the second order echoes are present, the apparent reflection coefficient is given by $\rho = \frac{2F''}{F'}$, where F' and F'' are the amplitudes of the first and second order echoes, respectively and where the reflection coefficient of the ground has been taken to be unity. However, second order reflections are not always present. But even for such occasions, the reflection coefficient, ρ, may be measured by employing the following method : At some previous time, when second order echoes are present (on the same frequency) the reflection coefficient (ρ_0), the amplitude of the first order echo (F'_0) and the equivalent height (d_0) of reflection are measured. With these data, the reflection coefficient at any subsequent time, when only the first order echo is present, can be determined, provided the receiving and the transmitting systems have been kept constant throughout. If F_1' be the amplitude of the first order echo and d_1 be the corresponding equivalent height, then the reflection coefficient is given by

$$\rho = \frac{F_1' d_1}{F_0' d_0} \cdot \rho_0 \qquad \ldots \quad (3)$$

As it takes an appreciable time to take one set of observations, the readings were not taken during sunrise and sunset hours ; during these hours ionization changes considerably within the time taken for observations and thus vitiates the results. The observations were, therefore, made during midday and night hours only, when the ionospheric conditions were expected to remain sensibly constant within the time taken for the readings.

Figures 1 to 5 depict the variations of attenuation with frequency as were measured at Calcutta on a number of days in March, April and May, 1952. The attenuation is plotted in db (given by $-20 \log_{10}\rho$) against frequency in Mc/s.

Figure 1 illustrates a typical case of variation of attenuation with frequency (and the corresponding P'-f curve) during midday hours. It will be noticed that for reflection from the E region, the attenuation has started increasing from well below the frequency (say about 4 Mc/s in the figure) at which the deviative absorption is expected to commence. This increase is due to the partial penetration of the wave through the E layer on account of its thinness. The attenuation rises more steeply as the E layer critical frequency is approached. For F layer reflections, the attenuation at first decreases with frequency due to decrease in non-deviative absorption. At points intermediate between E and F layer penetration frequencies, the decrease in non-deviative absorption seems to be completely balanced by the increase in the deviative absorption, and the attenuation remains more or less constant over a certain frequency range. Near the critical frequency the increase in deviative absorption is much greater and the overall attenuation increases. For frequencies very near the critical frequency of the layer, the increase in attenuation is much greater than that which can be accounted for simply by increased penetration into the layer. This high attenuation is due, at least partly, to a partial transmission of wave energy through the layer. This large increase in attenuation is observed during all hours of the day, for frequencies very near the F layer critical frequency.

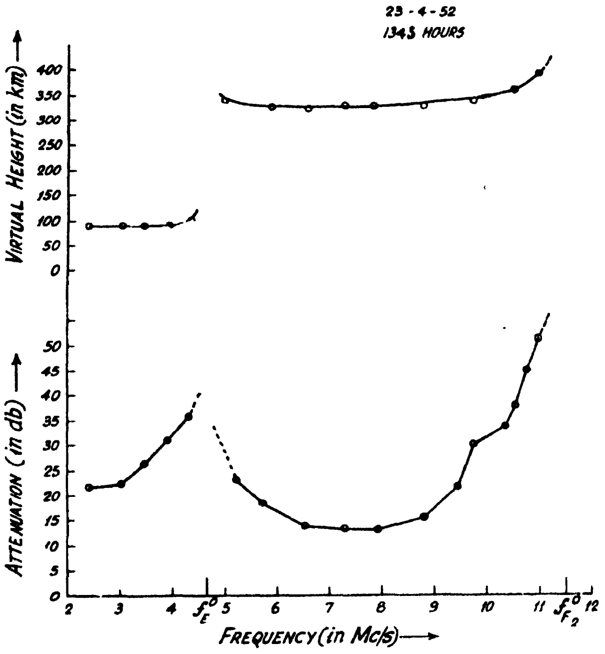

FIG. 1

Variation of absorption with frequency and the corresponding P'-f curve as observed on 23.4.52 at 13 hour 45 min. L. M. T.

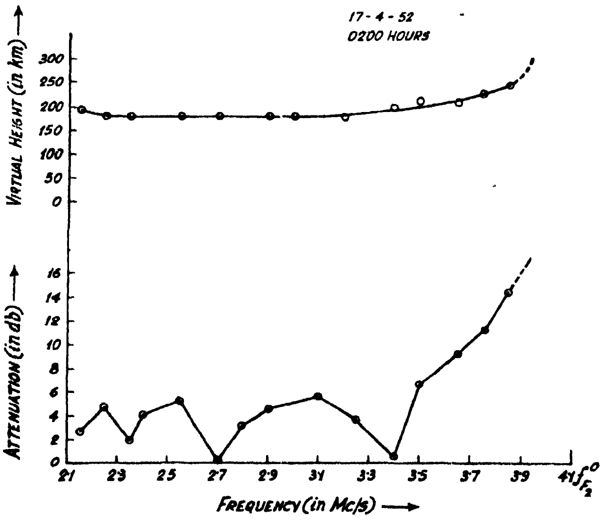

FIG. 2

Variation of absorption with frequency and the corresponding P'-f curve as observed at 02 hour 00 min. L. M. T. on 17.4.52.

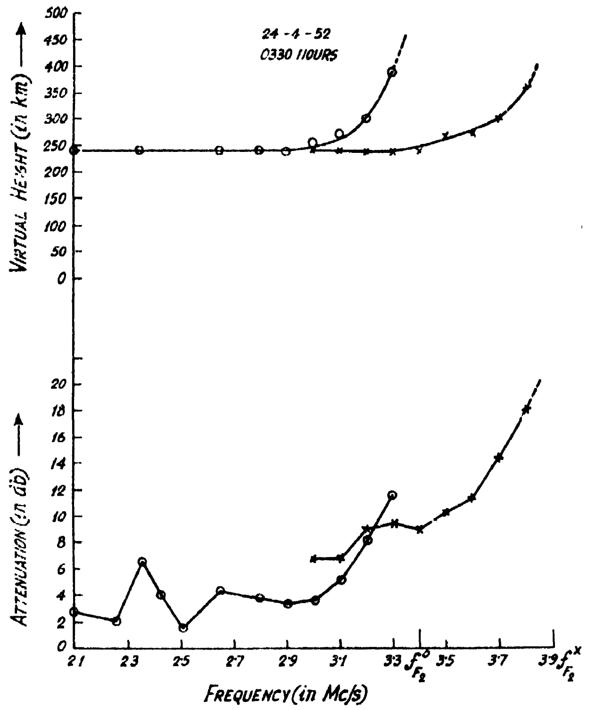

FIG. 3

Variation of attenuation with frequency and the corresponding P'-f curve as observed at 03 hour 30 min. L. M. T. on 24.4.52.

Figure 2 illustrates a typical night time absorption, during a quiet period and in the absence of E_s. Attentuation is very small (average of about 2 db compared to about 20 db, of figure 1), excepting near the critical frequency of the F layer. The random changes in the amplitudes of the echoes are however, much greater at lower frequencies : hence, the true attenuation at low frequencies is given rather by the mean curve and not by the point to point curve as drawn. Near the critical frequency, the echo amplitude becomes more or less steady, increasing the accuracy of observation.

Figure 3 depicts a typical night time absorption (also in absence of E_s) but with magneto-ionic splitting. The attenuation of the extraordinary component is (and was always found to be) greater than that of the ordinary component (excepting at the critical frequency for the ordinary ray). This is in conformity with the theory. Otherwise, the variations are as in figure 2 (Mitra, 1952).

Figure 4 illustrates a night time case when E_s was present. Upto the frequencies for which E_s echoes are present, there is increased attenuation of F echoes. As the collisional frequency in the E region is small, there is no appreciable absorption there. This increased attenuation appears to be due to partial penetration of wave energy and scattering at the sporadic

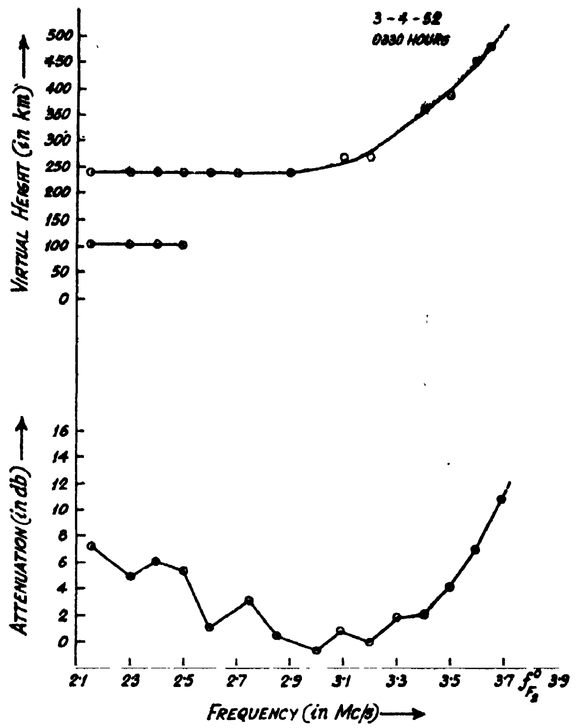

FIG. 4

Variation of absorption with frequency and the corresponding P'-f curve as observed at 03 hour 30 min. L. M. T. on 3.4.52.

E layer. In other respects the results are as in figure 2. The apparent attenuation is found to be zero or even negative at some points. This is explained as due to the 'focusing effect'.

Figure 5 illustrates a typical case at night on the eve of the formation of an ionospheric disturbance—a blanketting E_s. During the observation period there was only a transparent E_s of low ionization density which gradually developed into a blacketing E_s in about 15 minutes. The average absorption was much higher than in ordinary nights, being comparable to midday absorptions. The attenuation was extremely high below 2.3 Mc/s and above 3.5 Mc/s (near the penetration frequency of the F layer). The former attenuation may be explained as due to partial penetration and or scattering from the sporadic E layer as in figure 4 ; the latter attenuation is due to partial penetration of the wave energy in the F region as in the previous cases. But, the unusually high average absorption in the range 2.4 to 3.5 Mc/s, which is below the frequency at which there is partial penetration in the F layer and is above the E_s critical frequency (*i.e.* in the frequency range in which the wave completely penetrates the sporadic E layer), cannot be so explained. From the observations it seems that there was, at the time, an appreciable ionization in the D region (where

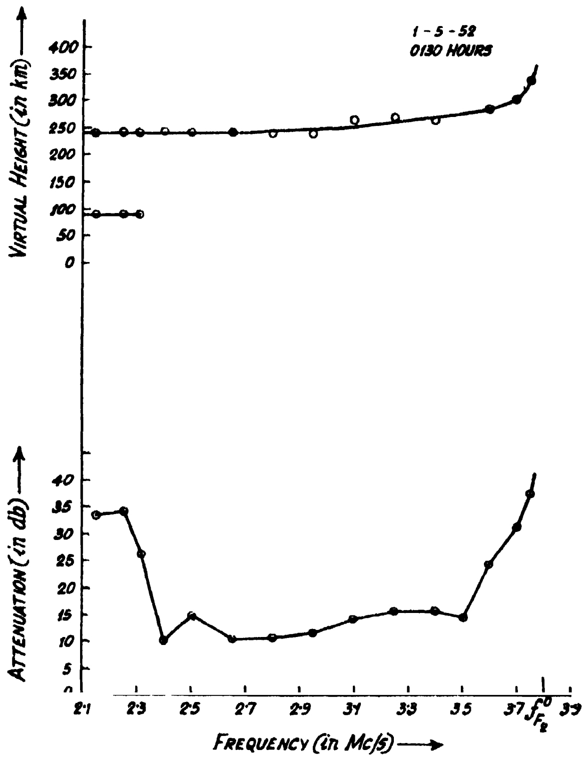

FIG. 5

Variation of absorption with frequency and the corresponding P'-f curve as observed at 01 hour 30 min. L M T on 1.5 52.

the collisional frequency is high). This alone can explain such a large absorption at all frequencies. Such night time formation of sporadic D layers at low latitude stations have also been reported by Ellyett (1947) and others.

It thus seems that the occurrence of night time sporadic D is associated with the occurrence of sporadic E, which is often observed at Calcutta in premonsoon and monsoon months when thunderstorms are frequent. It is therefore not unreasonable to suppose that the thunderstorm mechanism which produces E_s as suggested by Wilson (1925) (runway electrons and the strong field of the thundercloud-dipoles), may also be operative in producing increased D ionization. It may be mentioned in this connection that the observational data of Calcutta over a number of years show that there is definite correlation between the occurrence of E_s and the occurrence of thunderstorm during the premonsoon and monsoon months (May to September). The problem of the production of sporadic D ionization at night, its correlation with night time E_s, and with the occurrence of thunderstorms forms a subject of further study.

4. CONCLUSION

Results obtained in the previous sections show that there is partial penetration of the wave energy near the penetration frequencies of the E and F layers, there being more penetration *i.e.* less reflection for the former. Of the magneto-ionically splitted waves, the extraordinary component suffers higher absorption in conformity with theoretical calculations. The night time absorption is generally low as the normal D layer is absent at night. But the absorption becomes very high in certain nights and this has been explained as due to the formation of sporadic D's. The sporadic D's are found to be associated with E_s and thunderstorms (as observed in premonsoon and monsoon months in Calcutta for a number of years) and their origin may be due to thunderclouds, in the same manner, as suggested by Wilson for the formation of E_s.

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